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THE LOCALIZATION OF CUTANEOUS AND MUSCULAR SENSATIONS AND MEMORIES. A STUDY OF THE FUNCTIONS OF THE MOTOR AREA OF THE CORTEX OF THE BRAIN.[1]

BY CHARLES L. DANA, M. D.

IN 1888 I published an article entitled, "The Cortical Representation of the Cutaneous Sensations" (JOURNAL OF NERVOUS AND MENTAL DISEASE, October, 1888). In that article I stated that the clinical and pathological evidence so far collected showed that the motor areas of the cortex contain also the representation of cutaneous sensations. I stated also that the sensory centres for the different parts of the body appear to be larger and more diffuse than the motor. After reviewing the experimental, the clinical and pathological, the anatomical and embryological evidence, and the evidence from teratology, I said: "I am certain that no amount of scrutiny can explain away the numerous cases in which superficial cortical lesions have caused monoplegias and monoanæsthias." I believe that the accumulated experience since that time has entirely confirmed the position which I took, and I do not know of any one who now seriously contends that the motor areas have not also some sensory function. Dr. Bastian, in his work on "Paralysis, Hysterical and Functional," has well said, however, that while the sensory function of the so-called motor cortex is acknowledged, the exact nature of this sensory function remains yet to be determined. We have, I quite admit, yet to learn the part taken by these areas of the brain in tactile, thermal, muscular and pain sensations. Since my first article was written a considerable amount of evidence—experimental, clinical and pathological—has accumulated, and it has seemed to me that the time had come when I might again go over this subject and determine, if possible, more exactly the sensory functions of this much-disputed region. In an article contributed to this subject by Dr. Hale White (*Lancet*, September, 1893) the author states that the conditions necessary to furnish perfectly good evidence pathologically of the function of the central convolutions are very exacting: the lesion must be somewhat limited, it must be definitely localized, its nature must be known by a careful autopsical record, and the clinical phenomena caused by it must have been carefully studied. Very few recorded cases answer all the requirements; still, there are a few that were observed before my first article was written, and there have been some since that time. Besides this, there have been a number of cases in which a certain amount of positive evidence has been furnished—evidence which, so far as it goes, is absolutely to be depended upon. There have also been added a nnmber of careful experimental observations; so that I do not quite agree with Dr. White in saying that the time has not yet come for another critical study of cases bearing on the problem. At any rate, I have determined to collect and make such a study, and I present the fruit of my labors herewith. The facts which I have collected may be grouped in three classes: first, the experimental; second, the clinical and pathological; and, third, the purely pathological.

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[1] Read at a meeting of the New York Neurological Society, Oct. 2, 1894.

Experimental.—I would say at once that, so far as the experimental evidence goes, I shall not attempt to make a complete or critical analysis of the records. I would refer, those who wish to study this to the very complete and thorough article by Dr. F. W. Mott (*Brit. Med. Journal*, Sept. 23, 1893, p. 685). Dr. Mott's experiments were made upon monkeys. He excised certain parts of the motor area; or, rather, he simply cut the cortex from the white matter by introducing a brain-knife bent at an angle. He afterward tested the amount of paralysis and the defect in sensibility by the clip test, and he found that defective sensibility invariably occurred on the side opposite the lesion.

If the whole leg area were removed, there was paralysis of the opposite leg, permanent as regards the fine movements of the foot, diminished sensibility of the limbs to all forms of stimulus for some days after the operation, and permanent blunting of sensibility to the pressure of a weak clip fixed on the sole of the foot. This was tested on three animals. When the whole motor area was separated there was permanent paralysis of the hand and foot, and paresis of the other muscles. Such animals showed, for some time after the operation, defective sensibility; only very painful pricking or heat would cause a response, and the parts permanently paralyzed were also permanently anæsthetic. Dr. Mott infers from his experiments that a permanent defect of tactile sensibility, especially in the hands and soles of the feet, occurs after large lesions of the motor area, something akin to the paræsthesia of ataxia. He found in these cases degeneration of the internal capsule and the striæ medullares of the optic thalamus, with some degeneration in the corpus callosum. There was no degeneration in the posterior longitudinal bundle or the lemniscus, and there was no injury of the gyrus fornicatus.

In the article by Dr. Hale White, to which I have already referred, he states that Professor Schæfer has made similar experiments and has caused similar results. Professor Schæfer found that removal of a part of the anterior central convolution produced defect in sensibility as well as motion. He also observed that the area removed must be of a certain size in order to produce this sensibility disturbance; in other words, that the excision of a very small motor area might produce some motor defect without any detectible sensory defect.

Mr. Victor Horsley's experiments led to conclusions in the same line (*Nineteenth Century*, June, 1891).

Clinical and Pathological.—The clinical evidence which I shall present consists of four cases of my own and nineteen others collected from literature. The first two are taken from the records of Bellevue Hospital, and the descriptions are not sufficiently complete to make them of more than corroborative value. I present them, therefore, very much condensed.

CASE I. (personal).—Male, aged 46. History of syphilis ten years before. Patient developed headache, convulsions of the left side of the body, followed by general convulsions and coma. Recovery from the convulsions, with a residuum of complete left hemiplegia and complete hemianæsthesia. Death.

Autopsy showed a syphilitic gumma of the dura mater pressing into and involving the central convolutions. The gumma was located about the middle portion of the fissure of Rolando, and was about one and a half inches in diameter.

CASE II. (personal).—Male, aged 55. History of syphilis. Gradual development of right hemiplegia, the paralysis being considerable in extent, and associated with some loss of tactile and pain sensibility on the right side. Death.

Autopsy.—Tumor size of hen's egg in middle of left ascending frontal convolution.

CASE III.—My third case is one of exceptional interest, both as regards localization and because it shows the practical value of cerebral surgery—a thing about which some doubts have been arising lately.

The case was operated upon by Dr. Conway, and I expect him to report it in its surgical details later. I shall, meanwhile, describe only the medical side of the case. The history will, of itself, show the credit due to Dr. Conway's skill.

Sarcoma, involving hand and arm centre, paralysis, sensory symptoms, Jacksonian epilepsy. Operation. Great improvement.

Boy, aged 16. At the age of thirteen a blow was received on the head, followed in six months by general epileptic convulsions. Later these became limited to left side, with aura beginning in fingers. A year before operation left arm became gradually weaker, with pains and twitchings in it; intense headache; vomiting and optic neuritis developed. Examination May 29, 1894, showed

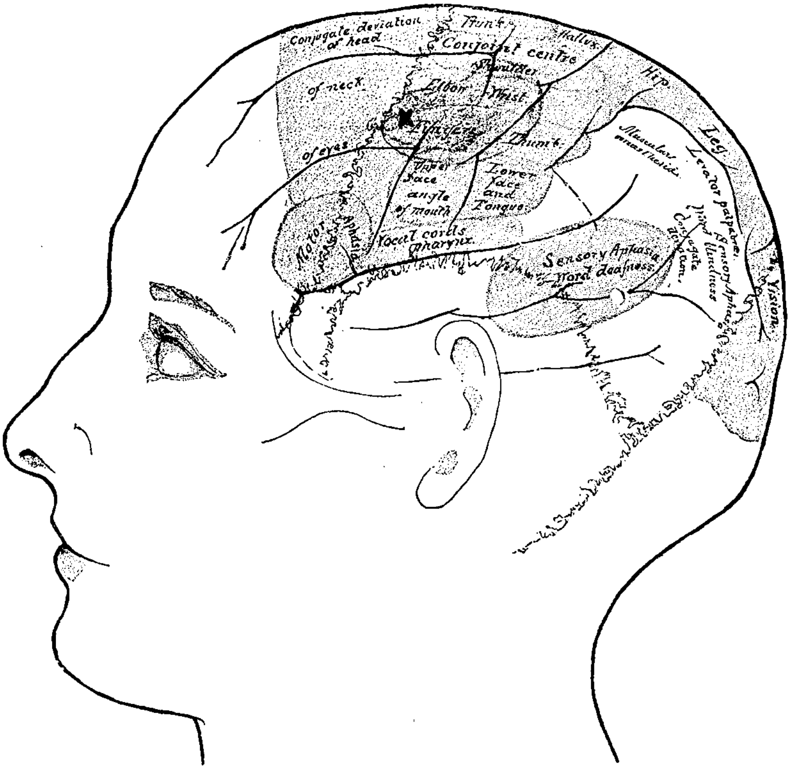


FIG. I. CASE 3. Location and extent of bone removed. At the point where the cross is made (x) the cortex is softened.

paresis of left arm, with very slight paresis of left leg and face; exaggerated reflexes on left side. Sensory condition: Left hand and arm showed diminished sense of contact and pressure; sensory circles enlarged to 2 ctm. (he felt two points as one in this area); localization of point on hand or arm touched defective; also, defective sense of position; cannot co-ordinate well (partly from paralysis); fumbling and clumsiness; weight sense defective; does not recognize nature of objects placed in hand; temperature sense normal; pain sense slightly exaggerated; no sensory troubles in the leg or face.

Operation by Dr. Conway: Trepanning over middle of anterior central convolution; removal of bone over an area three inches by two and one-half (see Fig. 1). Beneath the dura was found a flat tumor lying on pia, which is attached to it anteriorly; pia mater and cortex infiltrated posteriorly with whitish spots (this area did not react to an electrical current); anteriorly, over the base of the second frontal, the cortex is softened and destroyed by an infiltrating tumor, which is about one-quarter of an inch thick, and extends beyond the limit of the trephine opening. It could not be entirely removed anteriorly. Tumor was a spindle-celled sarcoma (Gouley), good recovery was made.

One month later: Pains gone, paralysis improved. Sensory condition practically as before, except that contact sense was improved; no pain; less hyperalgesia; reflex excitability less. Muscular-articular sensations slightly more impaired.

Four months later: Paralysis still less; sensory condition about same; no pain; no headaches; *optic nerve normal;* no convulsions. General condition excellent. Patient eloped.

One month later, Nov. 3, 1894, the boy returned, having had several epileptic attacks. He still has no headaches, or eye symptoms. The paralysis and sensory disturbances are about the same.

CASE IV.—Amelia B., age 17, single. When six years old had a fall and was struck on the left side of the head. This was followed a week later by a right-sided convulsion. Has since then had convulsions of an epileptic character with loss of consciousness, but always confined to the right side. They increased in frequency to one or two weekly. With them mental deterioration set in, and she became nearly imbecile. Her attacks were unilateral, and began in the right arm, which was raised over the head. Then the head and face and leg were involved. Lately the attacks became general.

Status presens.—There was slight weakness on right side, in arm and leg; no anæsthesia or ataxia. The knee-jerks were feeble on both sides, and so were the elbow-jerks.

She was operated upon by Dr. Robert T. Morris, on

September 26, 1894. He removed a piece of bone two inches by one and one-half from over the middle third of the anterior central convolutions, the area extending a little above the middle third and anteriorly over the base of the second frontal convolution. (Fig. 2.)

On removing the bone and opening the dura, both of which were normal, the brain tissue in the anterior part of the wound was seen to be dark and disintegrated. The extent of this could not be exactly ascertained without cutting into the brain unnecessarily. Its superficial area was about one inch in diameter, but might easily have extended down and forwards considerably. A strip one inch long and one-fourth inch wide was removed, and the wound sewed up.

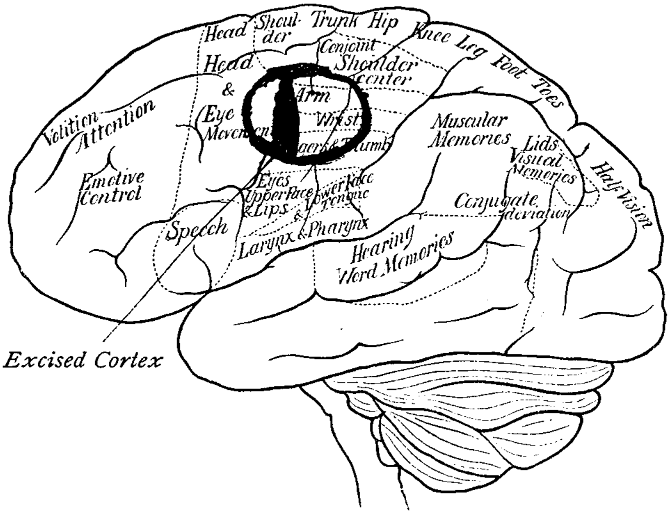


FIG. 2. CASE 4. Showing the area of bone removed and the position of the diseased cortex excised.

As this case is not reported for its general pathological and clinical interest, further details are not given now.

The wound was sewed up, dressings applied and the patient made a good recovery, thanks to Dr. Morris' skill.

Three days after operation she had had three right epileptic attacks. Examination at this time showed slight hemiplegia, most marked in lower half right face, less in right arm, least in leg.

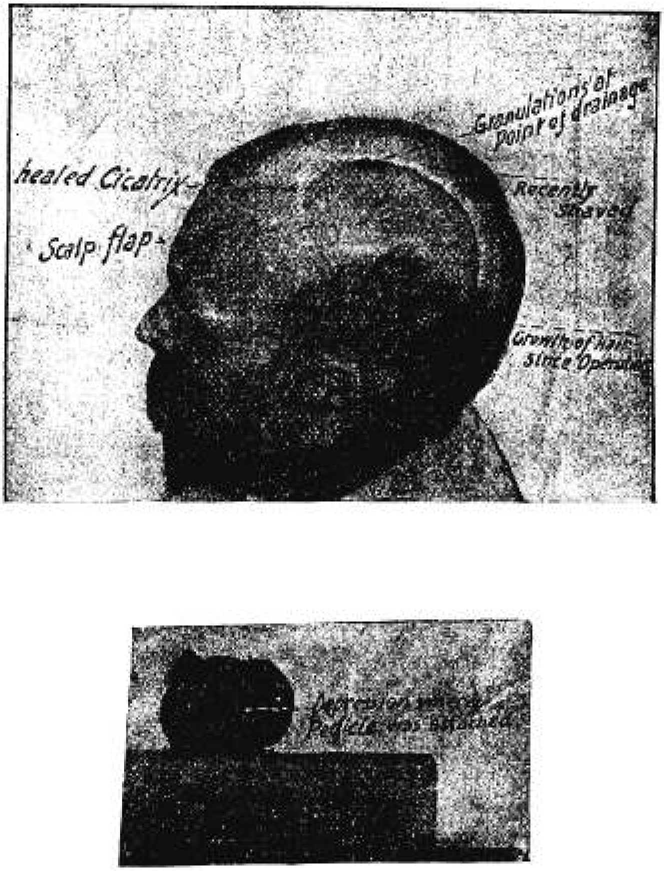


FIG. 3. CASE 5. Showing location and size of tumor in Dr. Steele's case.

Sensory.—Tactile anæsthesia was present in the right forefinger, where she could not feel a touch. It was slightly present on the rest of the hand, less still on the face; no anæsthesia of the leg. Analgesia was present in same area as the tactile anæsthesia. There was no heat or cold anæsthesia. There was great clumsiness and awkwardness in moving the fingers and arm, and a slight difficulty in localizing touch. She knew the position of the limbs and fingers.

She could not tell the nature of familiar objects placed in the hand. She could carry the finger to the point of the nose quite accurately.

The striking symptoms were the clumsiness and inability to handle and recognize objects, and the tactile and pain anæsthesia. Three weeks later slight paralysis remained, the sensory symptoms had disappeared, except a slight awkwardness (more than could be explained by the paralysis). She had had no more convulsions, she seemed brighter mentally, and was feeling well.

CASE V.—Male, aged 41. Gradual development of pain and parasthesia in right leg, with Jacksonian epilepsy. At the end of a year the whole right side was affected. Examination then showed right hemiplegia and "sensory blunting" of right side. General symptoms of brain tumor. Operation: A fibro-sarcoma two and one-half inches by two inches was "shelled out" from the region of the upper third of the Rolandic convolutions. (Fig. 3.) The tumor was attached to the falx by a pedicle, and "grew from the wall of the longitudinal ruins." From this point of origin, says Dr. Steele, it grew into the Rolandic fissure, displacing the paracentral lobe. After the operation "sensation was first felt in the shoulder muscles, the next day he could move the arm, and on the third day he could draw up the forearm; and now he has good control of the whole arm except the fingers. He has no power, and but little sensation, in the fingers." He was discharged improved, and improving.—Dr. D. A. K. Steele, *Journal of American Medical Association*, Jan. 27, 1894.

CASE VI.—This case is reported under the title of a tumor of the cortex, producing hemiplegia, with loss of tactile, pain and muscular sense. A man, aged 51, began to have local epilepsy in October, 1890, the convulsion beginning with parasthesia, and paralysis marked in left arm. He began to lose tactile, pain and muscular sense in the left arm and hand. Loss of tactile sense was absolute in the ring finger. The arm grew weak and the leg began to drag. Gradual increase of paralysis and general symptoms of brain tumor. Death in six months. Autopsy showed a softened melano-sarcoma 1 inch by 1¾ inches. "The tumor involved the posterior central, superior parietal, supra-sylvian anterior portion of angular and occipital convolutions of the right side." The special point is the simultaneous involvement of the arm and hand in paralysis and anæsthesia.—Dr. Frank S. Madden, JOURNAL OF NERVOUS AND MENTAL DISEASES, Feb., 1893, p. 125.

CASE VII.—Man, crush of skull just behind right parieto-frontal section, followed by delirium and left hemiplegia. Exploration showed fracture of base as well as vetex. Removal of bone and contused brain over an area four by three inches. No rise of temperature. Return of consciousness on sixth day. Temporary left facial hemiplegia. Paralysis of left arm and leg improved up to a point, so that he could walk well, and left arm showed "good average power." "Voluntary movements were performed with left limbs in extremely awkward manner. He had complete loss of sense of position in the leg, and incomplete in the arm." "He could move the muscles of his face, but could not make a specified movement." Eye muscles normal. "Sense of resistance almost absent." Sense of weight not tested. On the affected side he had sensation of very rudimentary description, these being only tactile (?) and painful sensibility. He could not locate a touch or feel what touched him, but he knew there was contact.

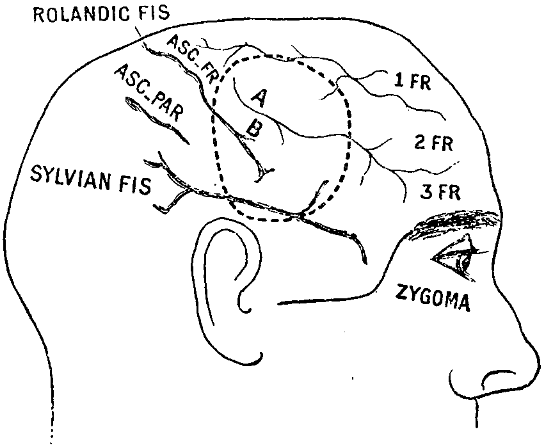


FIG. 4. CASE 7. Laycock. The dotted line shows the extent of the injury to the bone, the letters A and B are placed over the deepest part.

He felt a pinch as painful, but could not locate it.

Delayed sense of contact on face, less on arm. He could not distinguish heat from cold, but if the heat was great it caused a diffuse sense of pain. In the leg the symptoms were similar, but less marked. Other senses normal.

Says Dr. Laycock: "The following parts of the cerebrum would appear to be involved: Lower half of ascending frontal, greater part of sigmoid flexure, posterior third of lower and middle frontal and base of upper frontal. Also, the base of the corresponding part of the falciform lobe. The motor centre for the arm was principally involved. (Fig. 4.)

Electrical tests were made with the galvanic current, one pole on the neck, the other, a small olive-shaped electrode, was placed over the face, arm and leg centres. With currents of five to ten ma. parasthesic sensations were felt over the corresponding segments of the affected side. With stronger currents, 12 to 13 ma., both sides were affected, the right less than the left. There was no pain and no motor reaction. The negative pole gave far more definite results.

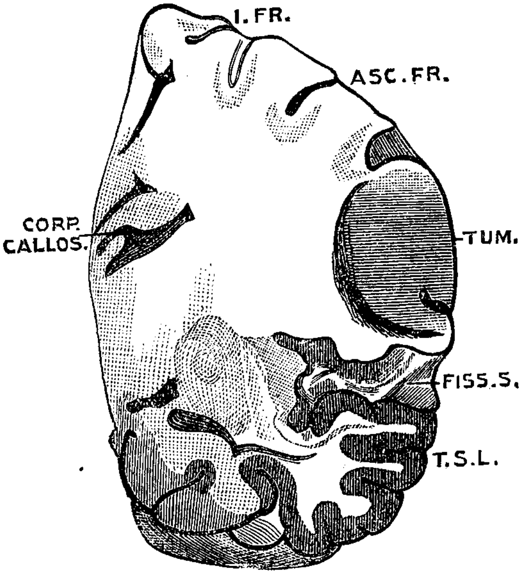
Later sensations of burning pain, cramp and weakness developed.—Laycock, *Australian Medical Journal*, July, 1893.

CASE VIII.—C. M., *æt.*, 68; tumor of the brain. Focal symptoms were weakness of the left leg, great weakness of the left arm and at the left angle of the mouth; exaggerated knee-jerks.

Sensory symptoms.—There were slightly diminished tactile, markedly diminished and altered painful, and much diminished thermal sensations all over the left arm and leg and left part of the face and trunk; the sense of position being also very imperfect in the arm and leg, especially the former. No hemiopia and no other affection of any of the special senses. Gradual increase of symptoms, and death about four weeks later.

Post mortem.—A tumor was found in the right hemisphere, the size of a walnut and hard in consistence, surrounded by a margin of softened brain tissue. It involved the cortex for about an inch and was situated about an inch above the lower end of the fissure of Rolando, entirely replacing the gray matter. The growth was limited to the ascending frontal and parietal convolutions, both of which it invaded at their lower ends. (Fig. 5.) There was white softening of the whole centrum ovale, which it may be assumed was of a date later than that when the examination that I have described occurred. The tumor was a scirrhous carcinoma. The history of the case showed that the disease began in the face centre. It was accompanied with epileptiform attacks which were associated with a sensory aura.—Dr. T. Wilson, *Lancet*, Feb. 27, 2892, p. 463. Service of Dr. Bastian.

Dr. Wilson says in comment: “In passing it may be remarked that the occurrence first of a sensory aura (pins and needles), immediately followed by clonic spasm in the same parts, is of interest in connexion with the theory that the motor area of the cortex contains sensory cells.”



Tracing from a photograph, actual size, of the vertical transverse section passing through the lower end of the right fissure of Rolando. TUM., Tumour. FISS. S., Posterior limb of the fissure of Sylvius. T. S. L., Temporo sphenoidal lobe. I FR., Superior or first frontal convolution. ASC. FR., Ascending frontal convolution. In the temporo-sphenoidal convolutions the gray cortex comes out well, but in the upper part of the section the details are very indistinct, owing to the white softening affecting this part.

FIG. 5. CASE 8. Scirrhus of brain.

CASE IX.—Male, 39. For two years Jacksonian epilepsy involving right leg chiefly, but with pain and spasm in right hand. Later, “constant and excruciating pain” in right hand and fingers, slight weakness of right side, right arm in rigid flexion, “tactile sensation fairly acute," skull opened over middle of left central gyrus and posterior part of third frontal. Small tumor lay on cortex. Cortex decorticated one fourth inch deep over area larger than a dollar in the anterior two-thirds of opening. Next day right hemiplegia most in hand, no more pain in hand. "Sensation fairly acute." Can't speak. On seventh day, less paralysis. "With closed eyes cannot locate a pin prick on right side, but feels it promptly and keenly." Later, relapse. Some return of pain and convulsions. Paralysis improved.—Drs. J. Frank and S. Church, *Amer. Journ. Med. Sciences*, July, 1890.

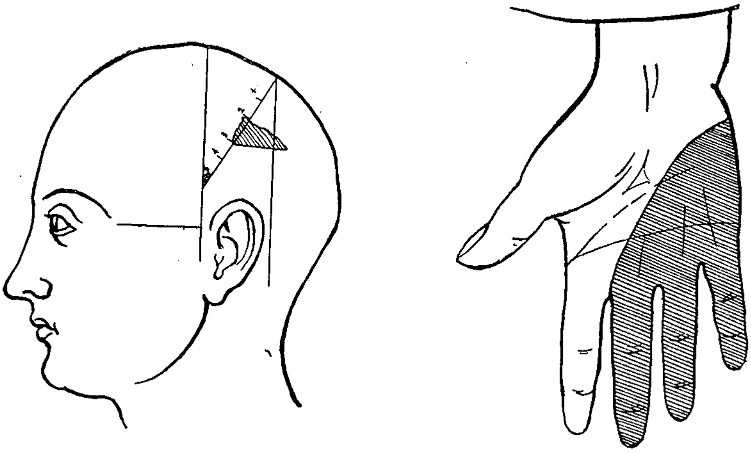


FIG. 6. CASE 12. Dr. J. Lynn Thomas. Showing location of scar with reference to fissure of Rolando, and the area affected with local hyperidrosis.

CASE X.—A patient with Jacksonian epilepsy and symptoms indicating cortical tumor. Operation; no tumor found. Resection of cortex for space one and one-half by one ctm. No fever. Patient developed a complete hemiplegia, which disappeared at the end of a month, "leaving only a slight anæsthesia and ataxia of the fingers, which prevented him from pursuing his occupation as a tailor." Dunin, *Verhandlungen, des X Intern. Med. Congress, Band IV., p. 11.*

CASE XI.—Male; cortical degeneration, result of an injury. Before operation, sensibility normal. During operation of trephining cortex of left ascending parietal on level with first frontal gyrus was somewhat lacerated. A small bit of cortex, three by six mm. and two mm.

thick, was excised. Entire injured surface had a diameter of not over one and one-half ctm. For at least seven weeks after operation patient had "anæsthesia of right arm up to elbow, for touch, pressure, motion and position, sensibility to pain, heat and cold was retained." There was also impairment of highly purposive movements, inco-ordination and a little athetosis.—P. C. Knapp, Intra-cranial Growths, p. 61.

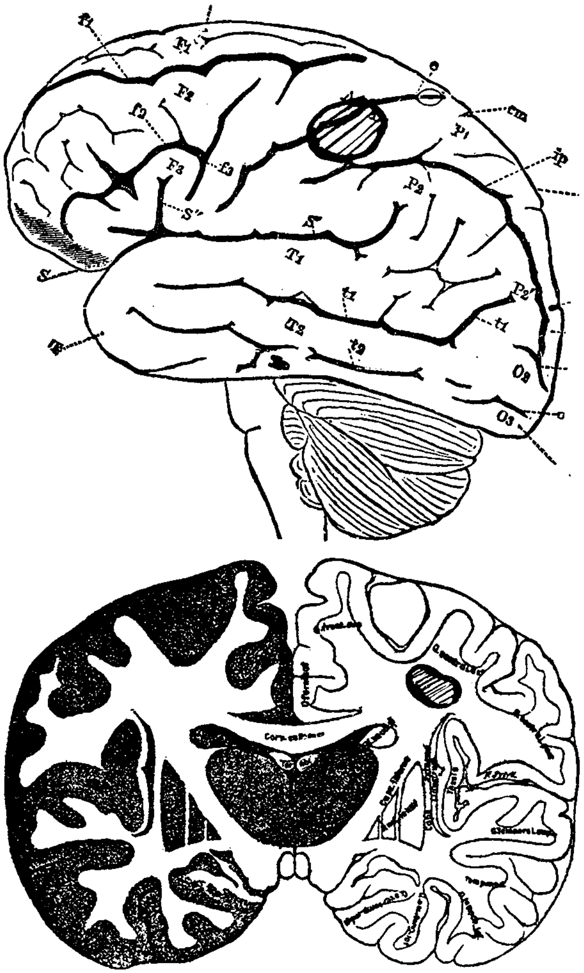
CASE XII.--Man, age 44. Received a blow on the left side of the head, causing a communated fracture. It was followed by a paralysis of the right shoulder and arm, with pain. Operation, with removal of bone and contused brain tissue. (Fig. 6.) The wound healed and paralysis gradually improved. Later it progressed again, and six months after the wound the situation was as follows: Weakness of left arm and hand; paralysis of the interossei and abductor of the little finger. Diminution of tactile sensibility in the upper third of the forearm. Two years later he could flex the fingers and use the hand to write. Tactile sensibility was lessened in the forearm and hand; sensibility to pain lessened in same region. Thermic sensibility slightly increased. Some hyperidrosis of the right hand.—J. Lynn Thomas, *Brit. Med. Journ.*, Feb. 24, 1894, p. 400.

CASE XIII.—Male, age 34, gradual development of right brachial monoplegia with symptoms of brain tumor. The lower extremity and face were not at all involved. Patient had phthisis. There was "a very marked diminution of sensibility of all forms, in the periphery more than in the parts near the trunk." No disturbance of sensibility, except in the arm.

Post mortem showed a tubercular tumor in the white matter just below the arm area of the cerebral convolutions. Its exact position is shown in the accompanying figures, taken from the original. (Figs. 7, 8.)—L. Darkschewitz, *Neurolog. Centralbl.*, vol. 9, 1890, No. 23.

CASE XIV.—Male, age 40. Traumatic hemorrhage of pia mater, compression of Broca's convolution and of middle central convolutions, aphasia, partial right hemiplegia and hemianæsthesia. Trephining. Clot found and removed. Arm totally paralyzed; tactile and pain senses impaired on paralyzed side. Three years after operation paralysis of right hand remains, "with marked diminution of tactile and pain sense. . . . The muscular and temperature senses are perfect." (Fig. 9.)—Starr, Brain Surgery, Case xviii, p. 161.

CASE XV.—Boy, age 12. Right hemiplegia with athetosis, due to fall at age of 2. Trephining by Dr. McBurney. Cavity in middle of anterior cerebral convolution incised and drained. After operation, hemiplegia the same; "the right hand as high as the wrist was decidedly anæsthetic to touch, temperature and pain, but there was no affection of the muscular sense." (Fig. 10.) One week later anæsthesia much less, athetosis gone.—M. A. Starr, Brain Surgery, p. 38, Case v.



FIGS. 7, 8. CASE 13. Showing location of tubercular tumor in Darkschewitz's case.

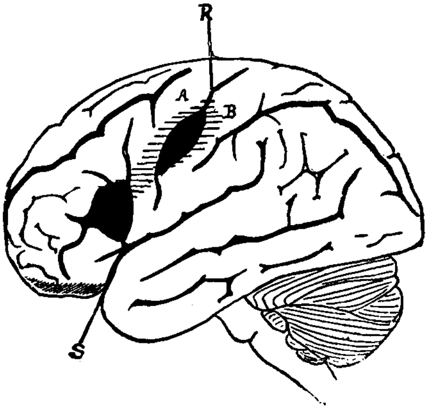


FIG. 9. CASE 14. Starr. Diagram of the Left Hemisphere of the Brain, showing the situation of the clot.

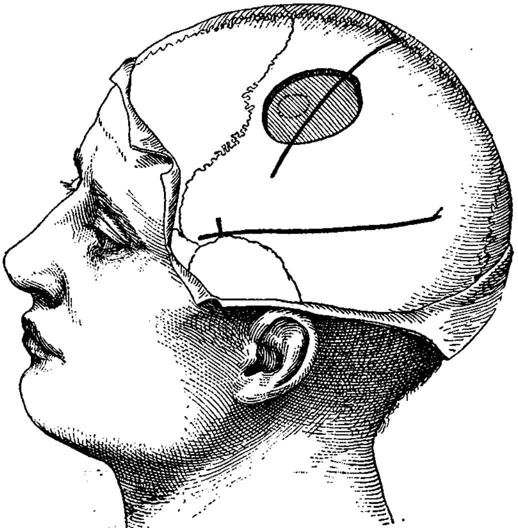


FIG. 10. CASE 15. Starr. The situation of the opening made in the skull.

CASE XVI.—Boy, age 15. Blow on head, followed in twenty-four hours by paresis of right arm and leg, but not of face or arms. "The grasp of the right hand was less than half that of the left. The pain sense while not destroyed was greatly inhibited. The temperature sense was somewhat interfered with. His arm could be moved, but none of the delicate movements of fingers, hand or forearm could be made. He could not tell the difference by touch between my silk handkerchief and the woolen blanket on his bed. A half dollar put in the palm of his hand he called a dollar. He said a wooden dumbbell, weighing half a pound, weighed about five pounds. The right foot, toes and leg were somewhat more paralyzed than the arm. The sensation was in nearly the same condition as in the arm."

Dyslexia, agraphia, intelligence good. He could only walk with help. Gradual intensification of symptoms with headache until fourth day, when operation was done. Depressed circular fracture formed as indicated in inner circle. (Fig. 11.)

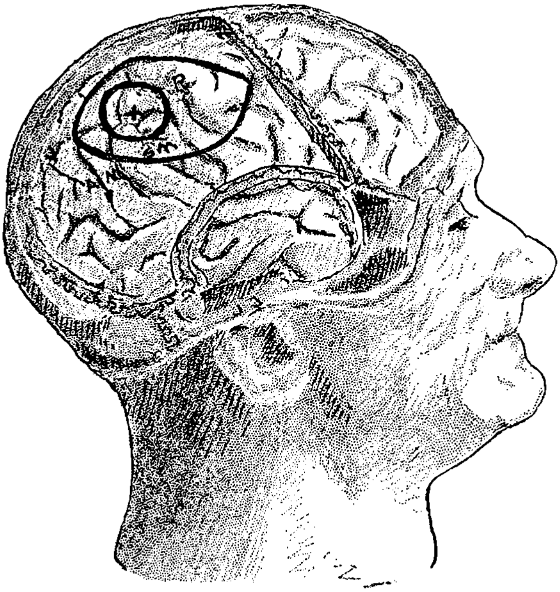


FIG 11. CASE 16. **Hudson. Showing location of clot.**

A tarry, firm, extradural blood clot three-quarters of an inch thick at centre of circle found and removed. Gradual improvement, the muscular sense being last to recover. He was well three months after operation.—Dr. W. H. Hudson, Annals of Surgery, 1893, p. 421.

CASE XVII.—Male, 25. Blow on head, followed by right hemiplegia and complete motor aphasia, with twitchings of muscles of right hand and arm. He experienced some sensation in arm and leg, but apparently *none in the face*." Operation second day, removal of intradural clot; three ounces of blood removed; clot was three inches square and a quarter of an inch thick. Button of bone removed; it was over base of third left frontal convolution. Complete recovery.—Dr. Herman Mynter, *Annals of Surgery*, May, 1894, p. 539.

CASE XVIII.—Male, aged 23. Compound fracture of the skull and wound of the arm centre. History of blow on the right side of the head, with compound fracture; marked depression and extensive comminution, the depression being at the centre of the Rolandic region. The left arm below the elbow was completely paralyzed. The intellect was unimpaired and sensation normal.

Operation three hours later. There was found a laceration of the surface of the brain three-fourths of an inch long, with slight loss of substance. After recovery patient had paræsthesia in left arm and leg. He developed hernia cerebri. Three months later the patient was found to have partial paralysis of the left arm and leg. Some time later the author states that examination showed still the presence of anæsthesia of the fingers and some rigidity of the forearm muscles.—L. L. Williams, *New York Medical Journal*, January 9, 1892.

Dr. Williams says: "Motion at shoulder almost normal; can flex and extend the elbow and wrist; pronation and supination perfect; can flex fingers, but cannot completely extend them. All of the fingers of the left hand are partially anæsthetic, but not analgesic. Perception of heat and cold is normal; the tactile sense alone is affected. He picks up articles with difficulty—fumbles with them as a child would. With his eyes shut he cannot pick up a book, and cannot distinguish between a knife and a pencil held in his hand.

He adds in comment: "The persistence of numbness in the fingers has been noted in a number of cases involving injury of the cortical motor area, and would appear to indicate, at least, a very close relation between the centres for motion and sensation. The inability to pick up articles with the eyes closed, and the awkwardness manifested in picking them up at all, seem to indicate faulty co-ordination, although these symptoms may be partly due to anæsthesia of the fingers."

CASE XIX.—The patient was a girl, aged 15, affected with Jacksonian epilepsy and progressive paralysis of left upper and lower limbs. Operation and removal of tumor the size of a hen's egg from the right central convolutions. Operation followed by paralysis, which greatly improved. Tactile, general, thermal, painful and muscular sense impressions, which before the operation were intact, were affected in a certain measure after the operation over the whole left half of the body except the face.—Albertoni and Brigatti, *Revista Sperimentale di Fren.*, *XIX.*, Jan. 1, 1893.

CASE XX.—Male, aged 18. History of a fall, followed by symptoms of development of cerebral abscess—headache, fever, hebitude. Four weeks after fall Dr. Nason says: "I noticed left facial paralysis and paralysis of the left arm, with impairment of sensation (chiefly tactile sensation) over the paralysed areas. The tongue also deviated slightly to the left when protruded. I thought, too, that the left leg did not move quite so freely as the right. There was no paralysis of the ocular muscles, and the pupils were equal and reacted to light." Operation: Trephining "over lowest third of fissure of Rolando." An abscess was found opening on the lower third of the ascending frontal; about an ounce of pus was evacuated. On the third day after the operation he regained power in the leg; next day, power and sensation in shoulder and arm. Pain in left arm, face still paralyzed. At the end of a week some power in left hand and partial return of sensation. Six weeks after operation "patient seems quite well, and but for fingers of hand being a little clumsy has completely recovered." Dr. Nason says: "The mode of recovery from the paralysis goes to prove that the various cortical centres are centres for associated movements and not for individual muscles; also, that sensation and motion are represented together in the central convolutions. It also would tend to prove that the centres for the various associated movements of the arm are placed from above downward in the following order: Shoulder, upper arm, forearm, wrist and hand, the thumb being lowest of all."

CASE XXI.—A woman, 55 years old. Gliosarcoma of the corpus callosum. The patient had suffered for two years from some trouble in walking, but she could use her arms. She finally became dull and apathetic, and was admitted to the hospital. There was then a condition of mental dullness, slight facial paralysis on the left side, slight bilateral spastic paralysis, with exaggerated reflexes. A very slight hemi-anæsthesia to pain obtained on the left side.

The post-mortem showed a very œdematous brain, with flattening of the convolutions. The two frontal lobes were united on their median surface. Upon the anterior portion of the corpus callosum there was a tumor which measured from one to three centimetres in diameter, and which grew on both sides into the brain substance, so that the total diameter of the tumor was from five to six centimetres. The centrum ovale was somewhat involved, and the observer thinks that the process might have affected the sensory part of the capsule. There was evidently an extensive destruction of the calloso-marginal gyrus on both sides, with practically no anæsthesia.—Redtenbacher, *Annual Report of the kk. Rudolf-Stiftung Hospital, 1891*, p. 66.

CASE XXII.—Man, aged 46. Tumor of the brain, involving the central convolutions of the left hemisphere. The patient suffered from local epilepsy, involving the right arm, and finally with a paralysis and anæsthesia of the right arm and leg.

Operation and removal of the tumor the size of a hen's egg from the middle of the two left central convolutions. The tumor was a sarcoma. After removal of the tumor sensation returned, and also some motion.—Dr. Carson, *Courier of Medicine*, 1891, p. 31.

CASE XXIII.—Male, aged 42. History: A blow on the head, followed by symptoms of the development of an abscess. Partial paralysis of left side, including face, arm and leg. Sensibility diminished in the left arm. Three days later, complete left hemiplegia, exaggerated reflexes, diminished cutaneous sensibility over arm, face and trunk.

Operation by Dr. Kelly. Trephining over the fissure of Rolando. A trocar was plunged downward and forward to the depth of two inches and six ounces of pus removed. Death followed. No record of nutopsy.—C. D. Roy, service of Dr. Peterson, *Southern Medical Record*, 1890, p. 456.

CASE XXIV.—Male, *æt.* 21. History of intoxication followed by aphasia with symptoms of dullness of tactile sensation in the fingers, the palm and back of the hand, and wrist. The whole of the right side, however, showed some defect in sensibility to touch, temperature, and pain, as well as of the muscle sense. Still it is stated that there was no ataxia in the right arm or hand. He could carry his right index to the tip of the nose, but he held the pen awkwardly and dropped it repeatedly. The symptoms increased, some paresis and some right hemiplegia developed, and the dullness of sensation increased proportionately.

Operation of trephining over the Rolandic fissure. A large subdural clot was found; this was removed, and the patient got well.

The sensory symptoms are specifically described as follows:

"Sensation (tested with a pin) is somewhat dulled on the whole of the right side. The main dullness is in the fingers, the palm and back of the hand, and the wrist; it is less higher up to the elbow and shoulder, and much less in the face. But, as just stated, the whole of the left side, including the leg, shows a defect in common sensibility. The same is true of the sense of temperature and pain. Passive movements of the fingers of the right side are not so well perceived as those of the left, showing a lowering of the muscle sense. The passive movements of the toes on the right side, however, are correctly stated. There is no ataxia in the right arm or hand; without hesitancy he carries his right index to the tip of the nose, the eyes being closed, and puts with precision the tip of the finger on the point of a pin.

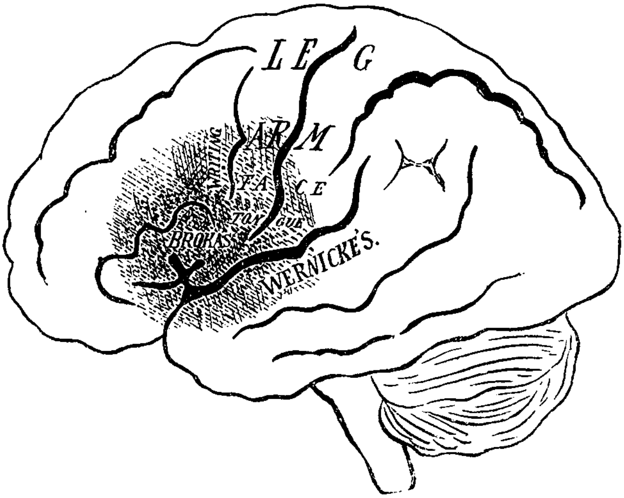


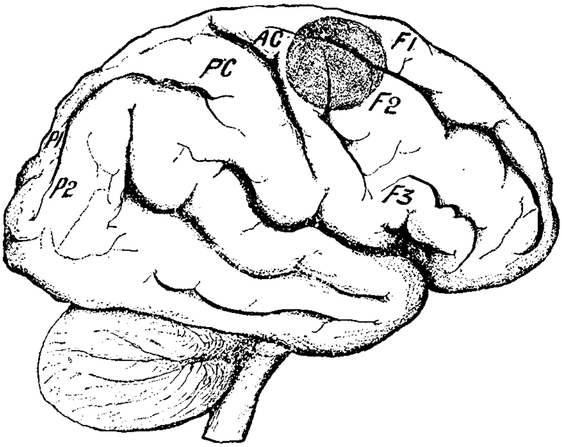
FIG. 12. CASE 24. Bremer and Carson. *American Journal of Medical Sciences*, Feb., 1892.

On the fourth day after the operation: "Sensation in right arm still impaired. Sharp points on right arm recognized as two points one and a half inches apart, or fingers two inches apart. Unable to feel blowing of breath on hands or arm."

Discharged cured in three weeks.

The localization of the lesion is given as shown in the accompanying diagram. (Fig. 12.)

Case XXV.—Male, *æt.* 60. History of the gradual development of a brain tumor with progressive left hemiplegia, most marked in the left arm. Sensation diminished in both arm and leg; at times both arm and leg would be almost devoid of sensation, at other times hyperæsthesia was complained of. Gradual development of a complete hemiplegia with increasing hebetude, coma, and death.



Case 25. Showing the localization of the tumor which was adherent to the dura mater.

Post-mortem.—A tumor, two and a half inches in diameter, was found involving the dura mater and the cortex of the middle of the precentral convolution and the posterior parts of the first and second frontal.—P. C. Barker, *New York Medical Journal*, June 25, 1892. (Fig. 13.)

Dr. Barker's words are, "Sensation diminished in both arm and leg. Dynamometer showed a loss of one-half in left hand." Later he adds, "The arm and leg became more paretic, sensation more disturbed. At times both arm and leg would be almost devoid of sensation (to pain and touch?); at other times hyperæsthesia was complained of."

An analysis of these cases shows first and indubitably that injuries and destruction of the motor cortex are accompanied by disturbance of cutaneous and musculo-articular sensations.[1] Before one can justly interpret the significance of these sensory disorders, we must agree upon some common interpretation of the significance of the tests used in making the examinations. My understanding of the matter and plan of proceeding is shown in the following paragraph. This may need some modification, but it will not, I think, be such as to essentially modify the conclusions.

I. The tactile sense gives us sensations of touch, impact, pressure, and of modifications due to extent and character of the surface, so that we recognize smoothness, roughness, etc. It is tested by bringing some object carefully in contact with the skin, or by pressure on the surface, or by the drawing rough and smooth objects over the skin.

2. The localization of objects touching the skin is done by means of an associative process, by which former experiences in touch are revived. In localizing an object the mental process is more complex than in simple appreciation of contact. While not strictly correct psychologically to say that tactile memories are revived, yet that term sufficiently expresses the idea. When a person loses his power of localizing a point touched, and thinks it is on the thumb when it is on the middle finger, he has a tactile amnesia.

3. The muscle-sense is dependent on the existence of sensory fibres in the muscles, joints and tendons. By it we appreciate the position of a limb, its active movements and its passive motions, *i. e.*, those made by another person. These sensations are tested in ways familiar to all, and their defects are shown in incoördination and inability to indicate determine weights and the position or degree of motion of a limb.

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[1] I have not attempted in this paper to deal with the negative cases, in which cortical injury occurs without apparent sensory disturbance. The number of such cases becomes yearly less.

4. A more complex "sensation" is that known as active touch. It is the process by which one appreciates the nature of an object that is placed in the hand or on the skin. Thus the patient is made to distinguish between different coins, or between a key and a nail, etc. In this process both the tactile and muscular senses are brought into play, and here associative processes are called into play.

5. Besides these we get thermal and painful sensations, the methods of testing which are familiar.

Now, in looking over the records of cases, it will be seen that the sensory losses most often observed are those in which the patient cannot localize an object, and in which he cannot tell the nature of an object; that is to say, he loses the localization power and the power of associating muscular and tactile sense, the power of active touch (Ziehen). Fumbling and awkwardness are clinical characteristics of destructive lesions of the motor cortex.

It is the associative power which is first and most impaired. After this we find most often tactile anæsthesia, then analgesia, then simple muscular anæsthesia, and least often loss of temperature sense.

This is in accordance with the evolutionary doctrine that the higher and more complex functions are more differentiated, more localized, and first affected by disease.

The simple tactile sensations are very diffusely represented in the cortex, and small lesions affect them slightly and temporarily, but the localizing power, depending on tactile memories, and the "active touch," dependent on motor and tactile memories, are each associated with the special cortical motor centre for the particular part.

In small cortical lesions, therefore, we have (besides the paralysis) a kind of amnesia, which may be compared to the motor aphasia which results when Broca's centre is destroyed.

Naturally, before a set of motor nerve cells is discharged in a voluntary movement this discharge must be co-ordinated and set off in a definite manner. The skin-muscular sensations stored up as memories[2] regulate these voluntary and automatic movements just as the word-memories regulate the organs of articulation. In cortical lesions there is then a skin and muscular "amnesia," and the patient with a cortical lesion is practically a case of motor-amnesia, so far as localization and certain purposeful movements in the affected part are concerned. The application of the same psychology to the central convolutions that is applied to that of Broca solves, as it seems to me, the much-mooted question of the motor-cortex and its functions.

The other and concomitant symptoms of analgesia and thermo-anæsthesia can be equally understood on this hypothesis. Painful and thermic stimuli help in teaching the motor-cortex to discharge correctly and purposefully. Pain and thermic memories would naturally cluster around memories of contact and motion, yet they are less specialized, less important, less effective.

The muscular sensations have their cortical representation, probably in the inferior parietal lobule and its neighborhood. But the awkwardness and fumbling movements in lesions of the central convolutions can be explained by the view I have suggested, that muscular memories or association processes are represented measurably, at least, in the motor area.

It does not follow from what I have said that I subscribe to the doctrine of Bastian and others, who believe that the central convolutions are sensory centres. They are essentially motor. Nor is it enough to say that the motor-cortex is sensori-motor, for this does not imply the fact thet the cortex represents not only sensations, but also memories of sensations. It is, in fact, a sensory-memory-motor organ.[3]

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[2] As already stated, the term memory is used to make the description harmonize with our ordinary terminology in describing the effects of cortical lesions.

[3] The terms, "perception" or "association-revival," areas are perhaps more strictly correct from the psychologist's standpoint than memory areas. But the word, memory, as ordinarily used by neurologists, answers the present purpose.